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PERFORMANCE OF COATED AND UNCOATED HORIZONTAL LAP- JOINT MEMBERS DURING 20 YEARS OF OUTDOOR EXPOSURE

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ABSTRACT

Horizontal lap-joint trials were set up using eleven different wood species representing a wide range of natural durability. Coated and uncoated lap-joint specimens as well as non-jointed reference specimens were exposed for up to 20 years and evaluated with respect to decay, formation of cracks and performance of the coating. The tropical wood species Tatajuba, Cedrorana, and Dark Red Meranti performed still very well and also some Europe-grown softwoods with coloured heardwood were still in good shape. The lap-joint set up turned out to be a method that can be used also for determining the durability and performance of untreated naturally durable wood, but suffered from several drawbacks such as time-consuming and costly specimen preparation, difficult to detect onset of decay, and generally long exposure times needed for a reliable durability assessment. Cracks were often the starting point for internal decay, but did not exclusively occur in the lap area.

KEYWORDS: Above-ground field tests, checking, coating, cracking, durability, use class 3.

INTRODUCTION

The durability of wood and wood-based products is significantly affecting the service life of wooden structures and commodities used outdoors. Hence, meaningful test methods are needed to determine the durability of wood in different use conditions, which allow to predict its performance over time. Durability tests can be conducted with single decay organisms or communities under defined laboratory conditions (e.g. CEN/TS 15083-1 & -2, 2005). Alternatively, field tests allow to take into account the full range of environmental parameters affecting the performance of wood in addition to its inherent protective properties. In contrast to in-ground exposures, the severity of above-ground exposures varies a lot (De Groot 1992, Meyer et al. 2017) and a multitude of test methods has been developed and applied to different wood products for determining their durability.

Horizontal lap-joint tests are among the few standardized field test methods for determining the relative protective effectiveness of a wood preservative exposed out of ground contact (prEN 12037, 1996, CEN/TS 12037, 2004, AWPA E16, 2013). The test specimens are composed of two elements forming a lap-joint with high potential for water trapping (Fig. 1).

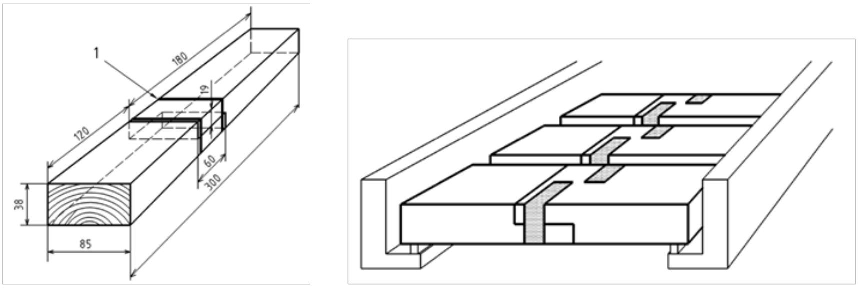

Fig. 1: Compositional drawing of lap-joint test specimens and exposure set up according to CEN/TS 12037 (2004).

The end grain opposed to the lap of the two elements is sealed for instance with a polyurethane, to mimic a longer wooden beam. The sealant is applied before impregnating the wood preservative and afterwards in case of defects to provide also a moisture barrier during outdoor exposure. Consequently, lap-joint specimens exhibit a gradient in preservative uptake with highest retention in the lap, and lowest close to the sealed end grain. This configuration has been frequently criticized for two reasons: 1.) the preservative concentration in the lap area is unrealistically high, and 2.) in case of cracking or defects of the end-grain sealing, the weakest part of the specimens, i.e. the part with lowest preservative uptake is exposed to moisture and fungal spores and likely the starting point for decay.

Lap-joint tests were not supposed to, but have frequently been used for testing also untreated wood (Clausen et al. 2006, Clausen and Lindner 2011, Lobb et al. 2011, Engelund et al. 2012, Meyer-Veltrup et al. 2017), modified wood (Temiz et al. 2006, Metsä-Kortelainen et al. 2011), and wood treated with water repellents (Sailer et al. 1999, Palanti et al. 2011, Terziev and Panov 2011, Brischke and Melcher 2015) to determineits (natural) durability. It has been frequently stated that the method is not sufficiently accelerating decay and takes too long to obtain results in an acceptable time span in particular in moderate or even sub-boreal climates (Grinda et al. 2001, Råberg et al. 2005, Metsä-Kortelainen et al. 2011, Palanti et al. 2011). Various measures to accelerate decay in above ground test situations were reported such as selecting tropical test sites, using shade boxes or exposing test samples under the canopy of forest trees (Meyer et al. 2016). Furthermore, the use of so-called feeder stakes made from non-durable wood species such as European beech (*Fagus sylvatica* L.) and pine sapwood (*Pinus* spp.) were used to initiate an early infestation of the test samples (e.g. Van Acker and Stevens 2003, Pfeffer et al. 2008, Cookson et al. 2014).

In 1996, the recently established lap-joint method for determining the relative protective effectiveness of a wood preservative was considered to be a promising instrument also for determining the natural durability of timber under field conditions and seen as a supplement for hitherto exclusively established in-ground testing using graveyard tests (EN 252, 2015;

AWPA E 7, 2013). Hence, eleven different wood species were submitted to horizontal lap-joint tests and exposed in Wageningen, The Netherlands, to study the suitability of the method for testing the natural durability of wood (Militz et al. 1998).

Similarly to the L-joint test method according to EN 330 (2015), where a defect coating is used to trap and accumulate moisture in a tenon - mortise joint, coatings were applied to lap-joint specimens within this study. However, a coating was applied on both, lap-joint specimens and non-jointed specimens, to see 1.) if the coating will either positively or negatively affect the wood durability, and 2.) to what extent the dimensional stability and durability of the wood will affect the performance of the coating itself. This study focuses therefore on the overall performance of the different wood species after 20 years of above-ground exposure.

MATERIALS AND METHODS

Material and above ground field test set up

Lap-joint specimens were fabricated from 11 different wood species (Tab. 1) as specified by prEN 12037 (1996). Therefore, specimens of 38 x 85 x 300 mm were prepared with a lap section of 60 mm length. Their end grain was sealed with a two-component polyurethane coating on the basis of acrylic resin and isocyanate (Sigmadur HB finish) before field exposure. In addition, specimens without a lap-joint were produced and exposed in parallel. For each species 12 replicate specimens were coated, 12 remained uncoated, and 8 specimens were made without any joint (4 coated; 4 uncoated). For the coating a primer on the basis of a urethane-alkyd (Sigma S2u primer) and a top layer from urethane-alkyd resin (Sigma S2u gloss) were used. The total thickness of the paint was 100-150 µm. The contact face between the two lap-joint members remained uncoated.

Tab. 1: Wood species, origin, density at 12 % wood moisture content (MC), and durability classs (DC) according to EN 350 (2016).

Wood species	Latin name	Origin	Density at 12 % MC ($kg \cdot m^{-3}$)	DC according to EN 350 (2016)*
Beech (B)	*Fagus sylvatica* L.	Netherlands	638	5 (4-5)
Cedrorana(CED)	*Cedrelinga catenaeformis* Ducke	Brazil	611	3
Light redmeranti (LRM)	*Shorea* sp.	Malaysia	411	2-4 (3)
Dark redmeranti (DRM)	*Shorea* sp.	Malaysia	581	2-4 (2)
Tatajuba (TAT)	*Bagassa guianensis* Aubl.	Brazil	833	(1)**
Sapele (SAP)	*Entandophragma cylindricum* Sprague	Cameroon	662	3 (3-4)
Scots pine sapwood (SPS)	*Pinus sylvestris* L.	Finland	538	5 (5)
Scots pine heartwood(SPH)	*Pinus sylvestris* L.	Belgium	510	3-4 (2-5)
Norway spruce (NSP)	*Picea abies* Karst.	Finland	463	4 (4-5)
Douglas fir (DOU)	*Pseudotsuga menziesii* Franco	Netherlands	512	3-4 (3-5)
Japanes elarch (LAR)	*Larix kaempferi* Lamb. (Carr.)	Netherlands	534	3-4 (3-4)

*DC based on results from laboratory or field tests with ground contact; in brackets: DC based on results from laboratory tests against basidiomycetes.

** Chudnoff (1984), and Tsunoda (1990)

The lap-joint test specimens were exposed according to CEN/TS 12037 (2004). Two lap-joints were fixed with cable strips and placed on test rigs of 1 m height with a minimum distance of 10 mm from each other. Specimens were put on aluminium spacers on the rigs to prevent direct contact with the wooden supports. Exposure started in September 1996 in Wageningen, Netherlands. In 2000, the specimens moved to the University of Göttingen, Germany.

Evaluation of field test specimens

The lap-joint specimens were evaluated with respect to decay, discoloration, and the formation of cracks in irregular intervals. Within this paper the results after 6, 11, and 20 years are presented. For the decay assessments the rating schemes according to prEN 12037 (1996) and CEN/TS 12037 (2004) were used as shown in Tab. 2.

Tab. 2: Rating scheme modified after CEN/TS 12037 (2004) for evaluation of lap-joint specimens (Ratings ‚2+‘ and ‚3+‘ were not used).

Rating	Description	Definition
0	Sound	No evidence of decay.
1	Slight attack	Visible signs of decay, but no significant softening or weakening of the wood.
2	Moderate attack	Areas of decay (softened, weakened wood); typically not more than 3 cm^2 and to a depth of 2 to 3 mm
3	Severe attack	Marked softening and weakening of the wood typical of fungal decay; distinctly more than 3 cm^2 affected and to a depth of 3 or 5 mm or 5 to 10 mm over a few cm^2
4	Failure	Very severe and extensive rot, joint member(s) often capable of being easily broken.

Note 1: Discoloration obviously due to the attack of wood destroying Basidiomycetes and/or soft rot fungi shall be recorded and mentioned in the test report. If recommended by the sponsor of the test discoloration due to staining fungi should be rated according to Annex C,

Table C.1

Note 2: Due to physico-chemical degradation of lignin defibration of the wood surface may occur at the upper surface of the lap-joints. Together with checks originating from differing wood moisture contents in different layers of the specimens their upper surface may be softened, especially when the Lap-joints are wet. This has to be distinguished carefully from fungal decay.

Note 3: In certain climatic areas with predominantly high relative humidity and frequent precipitation soft rot may occur in a thin layer of the upper surface, leading to softening of this layer.

The formation of cracks on the specimens’ upper surface as well as the defects of the outer coating were assessed visually and rated between 0 (no cracks) and 5 (severe cracking) and between 0 (coating fully intact) and 5 (coating completely destroyed).

A more detailed evaluation of all specimens was conducted after 11 years of exposure. It was assessed from where decay and the formation of cracks started and how it spread from there. The following options were distinguished: 1) starting from the lap, 2) starting from end-grain, 3) starting from lap and end-grain, 4) starting from the centre of the specimen, 5) starting point not identified, and 6) specimens not decayed.

RESULTS AND DISCUSSION

Decay developed significantly faster in lap-joint specimens compared to non-jointed members (Fig. 2). In contrast, coated lap-joint specimens decayed not significantly faster than uncoated ones, even though they had been wet for longer periods as previously reported by Militz et al. (2000). Similarly, no significant and general effect of the coating on decay was found with the non-jointed members. Merely, DRM and Sapelli showed slight attack if non-jointed specimens were coated, but no decay if remained uncoated (Fig. 2 C and D).

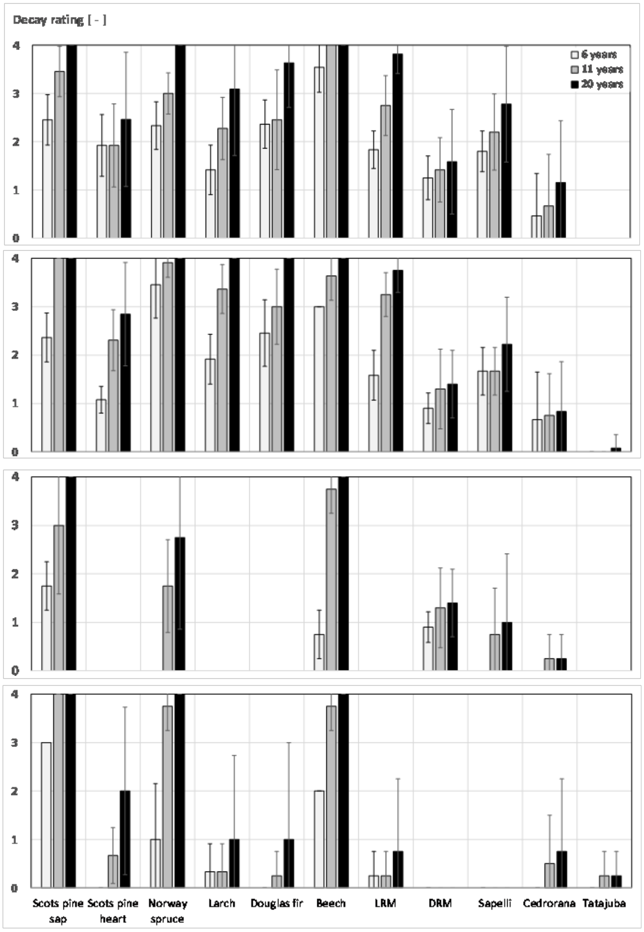

Fig. 2: Decay rating of different types of above-ground field test specimens. A. Coated lap-joints; B. Uncoated lap-joints; C. Coated specimens without lap-joint; D. Uncoated specimens without lap-joint.

In general, Tatajuba performed best and in total only two specimens showed slight signs of decay after 20 years of outdoor exposure. Cedrorana and DRM were also performing well, but showed significant decay already after 6 years of exposure. Solely, the uncoated and non-jointed DRM and Sapelli specimens showed no decay even after 20 years of exposure. The heartwood of Scots pine, Japanese larch, and Douglas fir performed well when exposed as non-jointed specimens, but showed decay to a similar extent as Norway spruce and Scots pine sapwood when specimens were lap-jointed (Fig. 2). According to EN 350 (2016) all three wood species are classified as moderately durable to less durable (DC 3-4). However, if water trapping joints are avoided they have the potential to perform much better than can be expected from the durability classification; i.e. no decay after 20 years of exposure in the non-jointed and coated specimens.

In the standard specimens, i.e. the uncoated lap-joint specimens, decay proceeded fastest in Norway spruce, which reached a mean decay rating (MDR) of 3.5 followed by beech (MDR = 3.0) and Scots pine sapwood (2.4). Similar results were obtained by Brischke and

Melcher (2015) who reported a MDR of 2.4 for Scots pine sapwood after 6 years of exposure in Hamburg, Germany. In contrast, Meyer-Veltrup et al. (2017) found that lap-joint specimens made from Scots pine sapwood decayed much faster in Hannover, Germany (i.e. all samples failed after five years), but performed better in Borås, Sweden, where a MDR of 1.5 was reached after 5 years of exposure. Furthermore, beech wood lap-joints failed completely already after 3 years in Hannover, whereas Douglas fir heartwood lap-joints reached only a MDR of 0.4 after 6 years in Goettingen. Norway spruce reached a MDR of 3.6 after 6 years in Hannover and 3.8 in Borås, which is similar to the decay rate obtained in Goettingen. In summary, the decay activity at the Goettingen site was similar to other locations in Germany and Sweden, but site-specific effects seemed to be superposed by material characteristics such as the susceptibility to cracking.

In general, after short and medium exposure time the lap-joint specimens showed more cracks than the non-jointed members (Fig. 3).

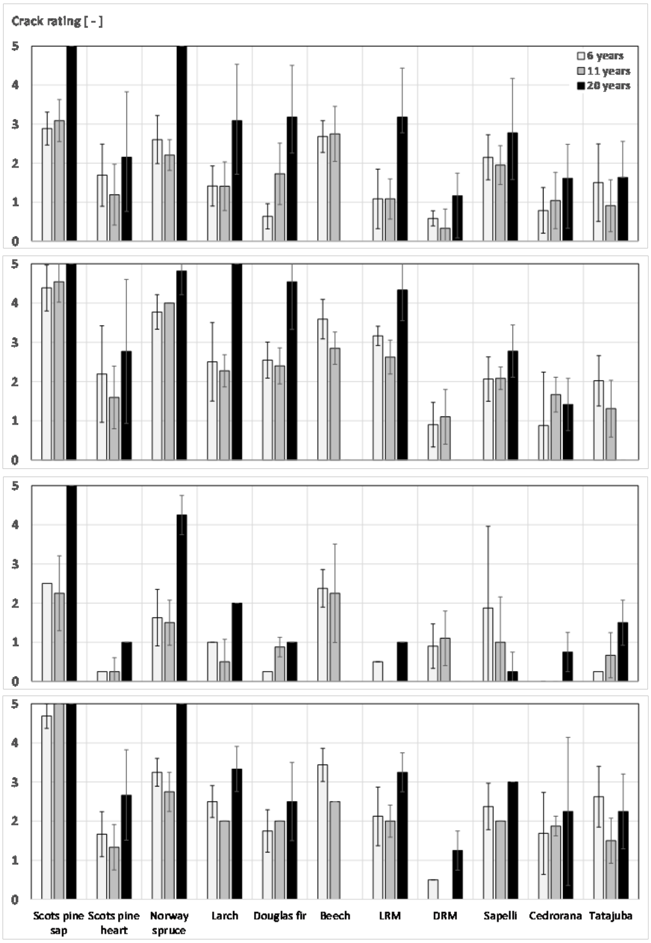

Fig. 3: Crack rating of different types of above-ground field test specimens. A. Coated lap-joints; B. Uncoated lap-joints; C. Coated specimens without lap-joint; D. Uncoated specimens without lap-joint. Asterisk indicates that all specimens failed previously and cracks could not be assessed.

However, after 20 years of exposure differences diminished. Furthermore, the coating failed on all specimens without an exception. A clear effect of the coating on the formation of cracks became evident only for the non-jointed members, where coating appeared to reduce the formation of cracks (Fig. 3 C and D). The performance of the coating itself did not support this finding, since significant defects of the coating were found already after 6 years of exposure (Fig. 4) and the coating was never renewed afterwards. As expected, the coating on the lap-joint specimens performed even worse due to moisture uptake through the end-grain in the lap area, but significant differences in the crack rating were not found between coated and uncoated lap-joints. Defective coating as it is used to accelerate decay in L-joint tests (EN 330, 2015) did not reduce the time till failure within this study, but apparently protected the solid and non-jointed specimens to some extent from decay even though the coating showed first defects already after 6 years of exposure.

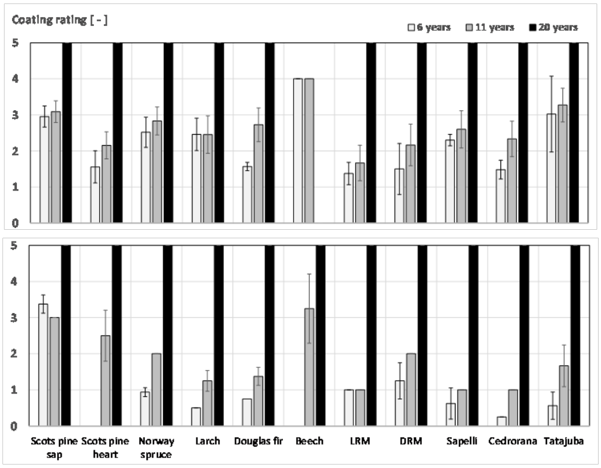

Fig. 4: Coating rating of different types of above-ground field test specimens. A. Coated lap-joints; B. Coated specimens without lap-joint.

As shown by Francis and Norton (2005) and Brischke et al. (2013) the application of a coating has the potential to drastically accelerate the decay ratesin L-joint specimens. However, in terms of relative durability, i.e. the decay rate of a wood species compared to a non-durable reference species such as pine sapwood, the application of coatings can have very divergent effects. This has been shown exemplarily for L-joint specimens made from Western Red Cedar exposed at ten different test sites in Australia (Brischke et al. 2013). In the majority of cases the coated specimens decayed faster than the uncoated ones and showed higher relative durability using also uncoated or coated reference specimens made from Radiata pine (*Pinus radiata* D. Donn.) sapwood.

The effect of a defect coating on the long term moisture performance of coated and uncoated L-joint specimens was examined by Meyer-Veltrup et al. (2017) who clearly found that the coating led to moisture accumulation and consequently to accelerated decay. The percentage time of wetness (ToW) determined as the number of days with a MC ≥ 25 % of beech, oak, Norway spruce, and Scots pine heartwood and sapwood was 43 % of the total exposure time in unpainted L-joints compared to 84 % in painted L-joint. Lap-joints, which were examined only unpainted had MC≥ 25 % at 64% of the total exposure time. On average the decay rate of the coated L-joints specimens was accelerated by more than factor 4 compared to uncoated L-joint specimens. The decay rate of the unpainted Lap-joints was 3 times higher compared to the uncoated L-joints (Meyer-Veltrup et al. 2017).

The lap-joint specimens examined within this study were monitored in terms of wood MC during their first 36 months of outdoor exposure by Militz and Bloom (2000) who found that the unpainted specimens suffered from higher MC fluctuations, but also longer times of wetness. Even though the whole lap area remained unpainted and thus a large area of freely accessible end grain was exposed to the water trap formed by the joint, the average MC of the unpainted lap-joints was usually less compared to the painted ones. As expected, the non-jointed specimens showed generally lower MCs compared to the lap-joint specimens. Apart from Scots pine sapwood, none of the non-jointed and painted specimens exceeded 25% MC during the first 36 months of exposure, which gives a clear indication that the moisture induced risk for decay was minimum and explains to some extent the overall good performance of this specimens configuration even after 20 years of outdoor exposure. Those specimens showing differently severe decay later on were likely affected by formation of cracks and defects of the coating which consequently led to higher moisture ingress and accumulation. Such negative effects of cracks on the moisture performance and as a consequence on the decay susceptibility of lap-joint specimens were previously reported for wax-treated lap-joints by Brischke and Melcher (2015).

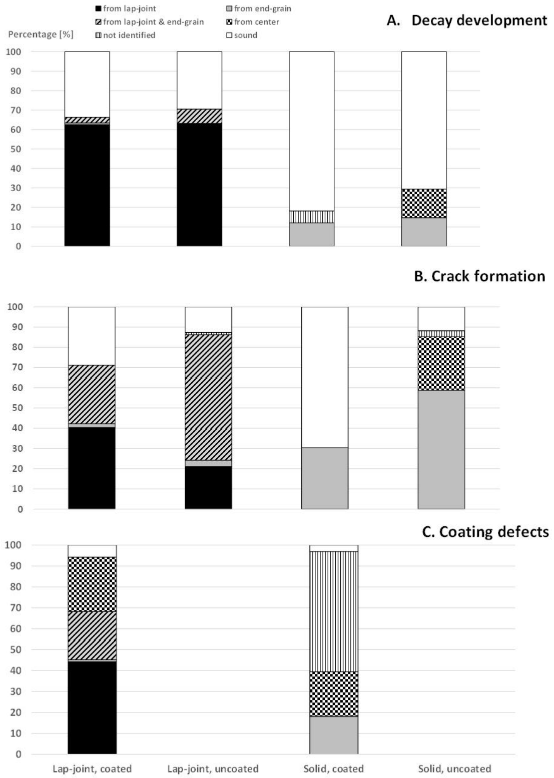

Fig. 5: Starting point for A.) decay development, B.) formation of cracks, and C.) defects of coating determined after 11 years of exposure.

After 11 years of exposure decay, cracks and coating defects were analysed also with respect to the part of the specimen where they were initiated. As illustrated through examples in Fig. 6 and Fig. 7 the lap area, the end-grain part, and the centre of the non-jointed specimens were the main starting points for both, decay and crack formation. Decay developed in the majority of cases from the lap area as it was supposed to do (Fig. 5), which stands in contrast to previous reports (e.g. Metsä-Kortelainen et al. 2011, Brischke and Melcher 2015, Meyer et al. 2016, Meyer-Veltrup 2017).

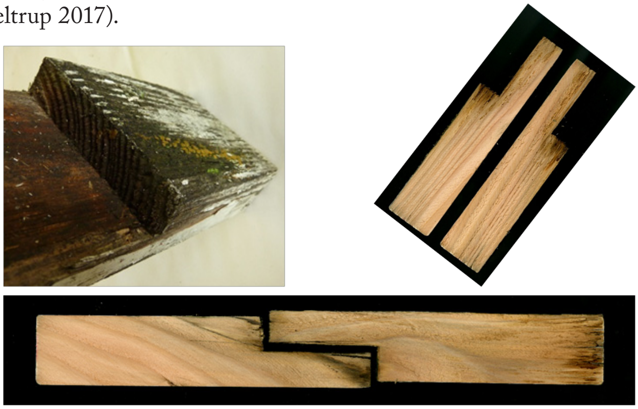

Fig. 6: Douglas fir specimens after 20 years of exposure. Top left: Opened lap-joint and fruiting bodies of Dacrymyces spp. on the upper surface. Top right: Interior brown rot decay starting from the lap-joint. Bottom: Douglas fir lap-joint with brown rot decay starting from the end grain.

Fig. 7: Top: Douglas fir non-jointed specimen after 20 years of exposure. Brown rot decay started from a long crack on the small surface and stopped approximately 10 mm beneath the surface. Bottom: Sapelli lap-joint specimen with severe cracking in one ofthe members, but no signs of decay.

In contrary, cracks also grew from the end grain part of the lap-joint specimens (Fig. 5), and coating defects occurred apparently not preferential. Nevertheless, decay was often initiated at the bottom of cracks independent from their location as exemplarily shown for a long and deep side crack in a Douglas fir specimen, which was the starting point for severe brown decay over the full length of the specimen, whereas the rest of the latter remained sound (Fig. 7). However, as shown for a Sapelli lap-joint in Fig. 7, cracks did not necessarily lead to onset of decay as long as the natural durability of the timber was sufficiently high.

CONCLUSIONS

The lap-joint set up turned out to be a method that can also be used for determining the durability and performance of untreated naturally durable wood, but suffered from several drawbacks such as time-consuming and costly specimen preparation and generally long exposure times needed for final durability assessments. Furthermore, decay did not always occur in the lap area and was difficult to detect beneath deeper cracks due to the comparatively large volume of the specimens. Coating of specimens led to improved performance if the specimens were non-jointed and the coating remains intact, but performance was reduced when a coating was applied to lap-joint specimens.

The findings from this study support the general perception that the horizontal lap-joint method is at least not ideal, but one of the few standardized above-ground methods used worldwide. Presumably, the frequent use of the method is due to the fact that it is standardized. However, more suitable above ground field test methods representing the different moisture conditions in above-ground exposure situationsare in principle available, but have not achieved acceptance among material scientists and approval bodies. Ideally, a standardized field test method should allow for testing naturally durable wood, thermally and chemically wood as well as preservative and water repellent treated wood. Therefore, further long term studies to determine the above-ground durability of wood are recommended using methods, which are less laborious and costly and allow fast and reliable detection of decay.

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